A Review of Research on Structural Holes and Innovation Performance

Bo Xu*

1School of Economics and Management, Nanjing University of Science and Technology, Nanjing, Jiangsu, China

Abstract. With the development of globalization, firms are facing increasingly fierce competition. In such an environment, innovation has become an inevitable choice for companies to survive and develop, and is a hot topic studied by management scholars. Especially in high-tech industries, innovation has a particularly prominent impact on a company's survival and prosperity. Technical innovation involves high levels of uncertainty and requires significant amounts of time and resources, so firms typically engage in strategic alliances to conduct joint research and exchange knowledge and information. In this process, innovation networks become an important source of innovation for companies, and the transfer, sharing, integration, and absorption of technical knowledge are all accomplished through innovation networks. As an important structure in innovation networks, structural holes can provide novel and heterogeneous information and knowledge. firms occupying positions in structural holes have information and control advantages, and by integrating different information, firms are more likely to create new knowledge. Therefore, the study of structural holes has become a focus of management research, and can play a significant role in promoting the development of social network and social capital theory. This paper systematically studies structural holes and innovation performance by reviewing existing research and defining the basic concepts and classifications of structural holes. In addition, relevant studies on the relationship between structural holes and innovation performance are summarized from the organizational, team, and individual levels, with a focus on the relationship between structural holes and firm innovation performance. Finally, based on the shortcomings of current research on structural holes and innovation performance, future research prospects are proposed to further promote the development of research in this area.

Keywords: structural hole; social network; innovation; innovation performance.

1. Introduction

Amidst rapid economic globalization, firms face intensifying competition. In such an environment, innovation has become essential for companies to not only survive and grow but also to achieve a competitive edge, particularly in high-tech industries where its impact is profoundly significant. Technical innovation, fraught with high levels of uncertainty and requiring substantial resources, often leads firms to form strategic alliances for joint R&D to facilitate mutual knowledge and information exchange. Within these alliances, innovation networks become vital sources of the firms' innovation, enabling the transfer, sharing, integration, and absorption of technical knowledge. In these networks, structural holes play a crucial role by providing access to novel and heterogeneous information and knowledge. Firms that occupy these structural holes gain informational and control advantages, enhancing their capability to integrate and create diverse knowledge.

The concept of "structural holes" is introduced by Burt in 1992 in his seminal book, "*Structural Holes: The Social Structure of Competition*." [1] This concept has since garnered significant attention from both management scholars and sociologists. For this paper, the term structural holes is used as keywords for advanced searches in Web of Science, filtering out literature from fields other than management and sociology. Using the Citespace tool, a co-occurrence analysis of the keywords is conducted to identify the focal points of research on structural holes. Figures 1 depicts the keyword co-occurrence maps from Web of Science searches on structural holes.

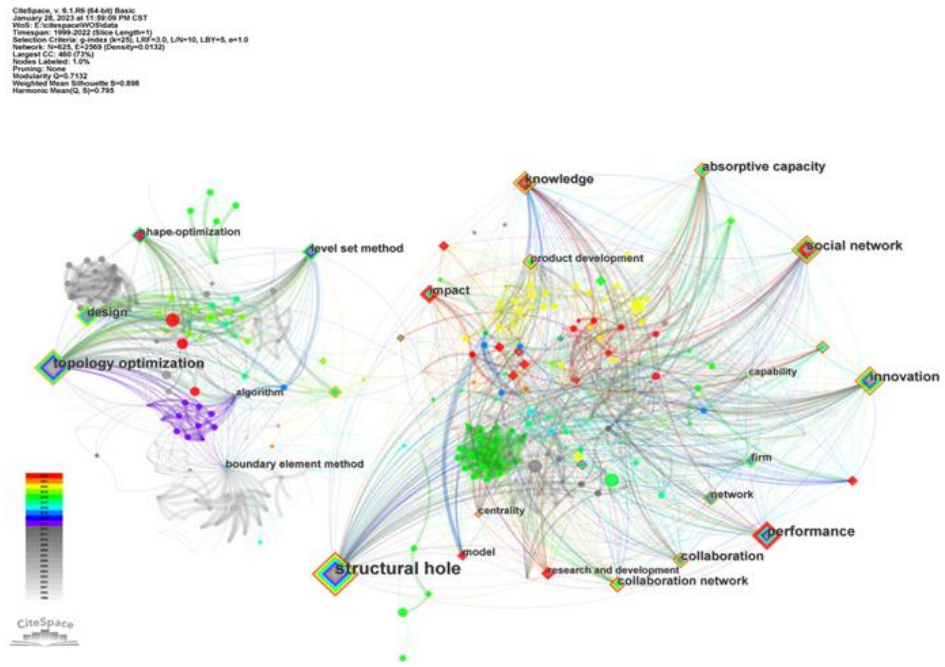

Fig. 1 Web of science Keyword co-occurrence

The visualization indicates that scholars prioritize themes such as social networks, innovation, innovation performance, and collaboration networks in their research on structural holes. This paper provides a systematic exposition of the concept and essence of structural holes and categorizes them accordingly and systematically discuss structural holes in relation to innovation performance. Moreover, the paper identifies existing gaps in the academic study of structural holes and proposes future research directions to advance the field's development.

2. Structural Holes

2.1. Theoretical Foundations of Structural Holes

2.1.1 Granovetter's Weak Ties Theory

Interpersonal relationships are an indispensable part of human society. Relationships can be broadly categorized into strong and weak ties based on the frequency of social interaction and the closeness of the relationship. The strength of a relationship is influenced by factors including the time invested, emotional closeness, intimacy, mutual confiding, and the linear combination of these elements that symbolize the tie. Strong ties are those close friends, partners, or clients who share many similarities, interact frequently, yet have a relatively small social distance and scope. In contrast, weak ties cover a broader social space with less frequent interactions. This phenomenon may relate to time, energy, and relevance of interests.

Granovetter introduced the concept of weak ties in his study on job searches [1]. He found that weak ties were more valuable than close friends in finding jobs because weak ties extend beyond one's immediate circle, providing access to a larger pool of information and opportunities, thus increasing the likelihood of finding employment. Despite being less stable than strong ties, weak ties have the advantage of cost-effective and efficient dissemination in today's data-centric society. Hence, establishing and maintaining weak ties is significant in professional and social contexts, facilitating access to valuable information and resources, and promoting personal and professional development.

2.1.2 Social Capital Theory

Social capital represents the resources embedded within social networks that can be mobilized, utilized, and transformed to fulfill various instrumental or affective ends. These resources play a crucial role at the individual, group, and societal levels. Social capital is applied across sociology, management, and economics, enhancing interactions and trust within organizations, exploiting

connections to external opportunities and information, and thus influencing organizational performance. However, the impact of social capital on organizational performance is dualistic; high levels of internal social capital may render an organization conservative and innovation-resistant, while high external social capital could lead to the leakage of confidential information.

Social capital research comprises three primary schools: the school of social norms, the school of network embeddedness, and the school of social resources. They study the relationship between social norms and social capital, the impact of social networks on social capital, and the resource value and liquidity of social capital, respectively. Chinese scholars like Nan Lin, Yanjie Bian, and Ruimei Xiong have also made significant contributions to this field. Overall, social capital research plays a pivotal role in understanding the relationship between social networks and organizational performance.

2.2. Concept of Structural Holes

The theory of structural holes, proposed by American sociologist Burt [1], emerged in his book "*Structural Holes: The Social Structure of Competition*" A structural hole refers to a gap in a social network where some individuals may have direct ties to certain others, while indirect or no ties exist to different individuals, creating a metaphorical hole in the network fabric [2].

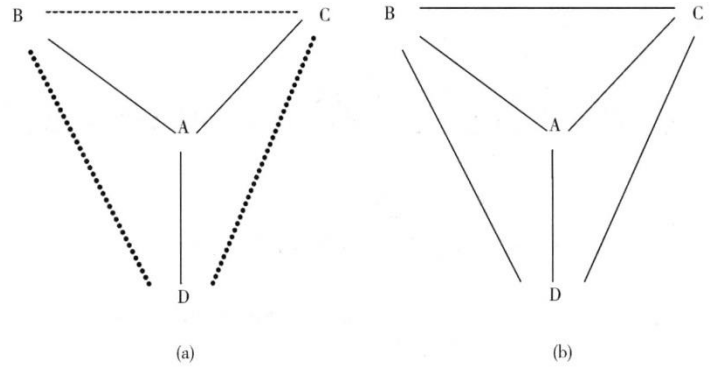

Fig.2 Comparison of Networks with and without Structural Holes

The above figure demonstrates the difference between networks with and without structural holes. In figure 2(a), nodes B, C, and D lack direct connections and must go through node A to communicate, thus creating structural holes between them. Node A, consequently, holds a competitive advantage by being central to the network and closest to all resources. Burt argues that structural holes, or the spaces between non-redundant social groups, potentially offer informational and control benefits to the actors (nodes) bridging them [2]. These benefits provide actors with unique and diverse information and timely access to sources. Control benefits enable actors to obtain greater bargaining power and control over resources or outcomes. Actors like node A, who bridge many structural holes, tend to acquire key resources and control over other actors, thereby exhibiting superior performance compared to those bridging fewer holes. In contrast, figure 2(b) shows a network where node A does not possess a competitive advantage as all nodes are equal, with direct connections to each other.

3. Classification of Structural Holes

3.1. Primary and Secondary Structural Holes

Structural holes are a key concept in social network analysis, often used to describe an individual's position and influence within a social network. Primary structural holes refer to gaps or absent connections in an actor's egocentric network—the key missing links within one's social web. The existence of these holes allows an actor to access different social groups, garnering a wealth of information and resources, thus enhancing their social influence and control.

However, the benefits provided by primary structural holes may be affected by peripheral or secondary structural holes. Burt introduced the concept of secondary structural holes in 1992,

referring to the absence of ties between an actor's secondary contacts [1]. These secondary holes can deepen the structural void, favoring the focal actor in gaining information and control benefits. In other words, secondary structural holes denote a lack of connections between those linked to an actor, potentially making the actor more distinct and prominent in the social network and yielding higher social influence and control.

It is noteworthy that different types of structural holes may yield varied outcomes for actors. For instance, primary structural holes are typically seen as the "weak ties" in a social network, facilitating the speed and breadth of information transmission, promoting innovation, and diffusing knowledge. Secondary structural holes, on the other hand, often embody "strong ties" that enhance the focal actor's standing and influence within the network but may also lead to localized and homogenized information. Therefore, when researching the impact of structural holes, one must consider their type and function to better understand and apply methods and theories of social network analysis.

3.2. Virtual Structural Holes

With the rapid development of the internet and information technology, the number and scale of users in virtual social networks have surged. The myriad activities conducted on these networks—such as socializing, online collaboration, and information sharing—provide researchers with an abundance of valuable data resources. Against this backdrop, research on virtual structural holes has deepened, touching upon broader domains and more profound issues. For example, researchers have begun to explore the characteristics and differences of virtual structural holes across various social media platforms and to investigate the trends and evolutionary patterns of different virtual social networks. The application of virtual structural holes is also becoming more widespread; beyond mapping the interruptions in social relationships, they can also predict information dissemination paths, assess the stability and security of networks, etc. Moreover, research into virtual structural holes involves many new technologies and methods, such as machine learning and natural language processing, whose applications promise to further drive the development and application of virtual structural hole theory [3].

3.3. Self-Benefitting and Mutual-Benefitting Structural Holes

Sheng and Fan have classified structural holes within innovation networks based on the intent behind their creation into self-benefitting structural holes and mutual-benefitting structural holes . Both share the common feature of certain actors in the social network having direct ties, while others are disconnected, creating gaps resembling holes within the entire network, as shown in the figures below:

In self-benefitting structural holes, the occupant of the hole, Actor A, actively connects B and C, but the purpose is for their own benefit to obtain informational and control advantages rather than to facilitate the overall flow of resources in the network. These types of holes typically exist among stakeholders dominated by competitive relationships.

The advantage of self-benefitting structural holes is that individuals or organizations can access information and resources from different directions, gaining support and recognition across various social groups, thereby enhancing their influence and power. For example, a sales manager who establishes a broad interpersonal network within a company, commanding information and resources from both inside and outside the department, can better respond to market changes and business needs, achieving personal performance growth.

However, there are disadvantages to self-benefitting structural holes. An excessive focus on relationships within one's own network may lead to neglecting external information and resources, causing important opportunities to be missed. Additionally, due to the relatively singular source of information, individuals or organizations may become entrenched in their traditional thought patterns and work methods, lacking a diverse perspective and innovative capacity.

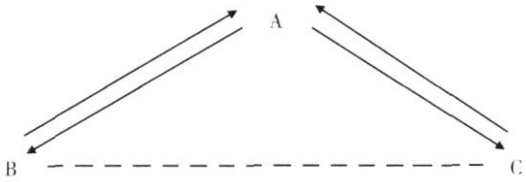

Fig.3 Self-Benefitting Structural Holes

In mutual-benefitting structural holes, B and C in the network wish to establish ties but cannot directly connect due to cost-benefit principles or other reasons, necessitating the intermediary role of Actor A. Here, the occupant of the hole, Actor A, is passively involved with the aim of facilitating the distribution and flow of resources within the network. These holes predominantly exist among stakeholders guided by cooperative relationships.

The advantage of mutual-benefitting structural holes is that they create opportunities for cross-disciplinary cooperation, enabling people from different fields to collaborate, driving innovation and the exchange of knowledge; they expand informational resources, allowing individuals to acquire useful information from various sources, valuable for both work and personal life; they enhance social capital, as members can establish ties with different social circles, which help increase personal social capital and thereby enhance social influence and organizational performance; they provide a broader range of opportunities, allowing individuals to encounter more people and chances, which helps expand their horizons and improve their career development and personal growth.

The disadvantage of mutual-benefitting structural holes is that they increase communication and coordination costs. Since the members come from different social circles, they may have cultural and cognitive differences, requiring more effort in communication and coordination. They may also bring competitive pressures as members often face competition from different social circles, which can affect individual performance and outcomes. Furthermore, they may lead to information asymmetry, as members can access information from various sources, but the authenticity and accuracy of the information can be difficult to guarantee, possibly leading to asymmetry and affecting the accuracy and effectiveness of individual decisions.

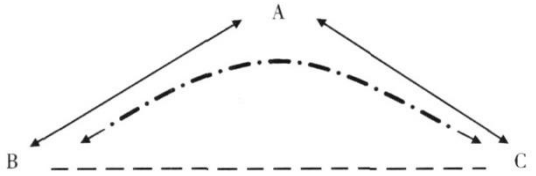

Fig.4 Mutual-Benefitting Structural Holes

4. Structural Holes and Innovation Performance

4.1. Measurement of Structural Holes and Innovation Performance

Burt introduced the Network Constraint Index in 1992, a measure indicating the level of constraints a focal firm experiences in its connections with other firms—the higher the index, the fewer structural holes and the greater network closure [2]. The constraint C_{ij} that a focal firm i experiences due to another firm j is given by:

$$C_{ij}=\sum(1-\sum P_{iq}P_q) \tag{1}$$

where i is the focal firm, j is another firm, and q is a different connected firm. P_{ij} represents the proportion of i's relational investments in j. P_{iq} is the intensity of the focal firm's relationship with q, and P_{qj} is the intensity of q's relationship with j. $\sum P_{iq}P_{qj}$ represents i's indirect relational investment in j. C_{ij} is the constraint, representing the investment of time and energy by i in j. The overall constraint C_i in i's ego network is the sum of C_{ij}:

$$C_i=\sum C_{ij} \tag{2}$$

C_i is the sum of constraints within the ego network of i. Network constraint reaches its maximum value of 1 when j is i's only contact and its minimum when i and j have no other indirect contacts, represented by P_{qj}^2. Network data for this calculation is typically analyzed using UCINET, social network analysis software.

As a proxy for knowledge innovation performance, the number of patent applications can be publicly obtained from national patent offices. Importantly, the quantity of patent applications reflects the future development capacity of firms, making it suitable for empirical studies that examine the output level of firms in knowledge innovation activities. When an entity files a patent application, it indicates that the knowledge innovation activity is complete, as the authorization phase is just procedural. Therefore, innovation performance is generally evaluated by the number of patent applications filed. However, this method is not applicable if innovation is categorized as exploratory or exploitative. Zang contends that if a firm cites patents that have never been cited before, its innovation is based on new knowledge [22]. Thus, exploratory innovation is represented by the proportion of citations in a company's citation list that have not been previously used, given by the formula:

$$EO_{it}=(NC_{i,t+1})/(TC_{i,t+1}) \quad (3)$$

where EO_{it} is company i's exploratory innovation in the focal year t, $NC_{i,t+1}$ is the number of new citations by company i in year t+1, and $TC_{i,t+1}$ is the total number of citations for patents applied by company i in year t+1.

When a company uses citations that have been employed over the past five years, it may indicate a profound understanding of these references and an endeavor towards incremental innovation. Thus, exploitative innovation is measured using the average number of times each citation used in the past five years has been cited, expressed as:

$$EI_{it}=\sum_{k=t-4}^{t} RC_{i,k}/TC_{i,t+1} \quad (4)$$

It should be noted that the measurement of exploratory and exploitative innovations is not limited to the above methods. Zhang et al. measured these types of innovations using the scales developed by Jansen et al. [29,31].

4.2. Levels of Research

Innovation is of vital significance to both firms and individuals, and research surrounding structural holes and innovation can be divided into personal, team, and organizational levels.

At the individual level, Hargadon et al., based on ethnographic research at the product design company IDEO, which included observations, interviews, informal conversations, and archival data, found that designers occupying multiple structural holes could integrate different technologies to produce innovative new products [4]. Gargiulo et al. studied a special department newly established within the Italian subsidiary of a multinational computer manufacturer and showed that managers with dense communication networks were less likely to adapt these networks to the coordination demands of new tasks, whereas structural holes could enhance managerial flexibility in the face of new challenges [5]. Regans et al. discovered in their study of the knowledge transfer process within network structures that strong ties crossing structural holes made the transfer of knowledge between individuals easier [6]. Tortoriello investigated how individuals within organizations use external knowledge to generate innovations [7]. Using original sociometric data collected from 276 scientists, researchers, and engineers in the R&D department of a large multinational high-tech company, it was shown that the impact of external knowledge on individual innovation depends on the individual's position within the internal social network. When individuals acquiring external knowledge crossed structural holes in the internal knowledge sharing network, the positive impact of external knowledge on innovation became more significant. The intermediary position is advantageous for individual innovation utilizing external knowledge because it offers opportunities for creative knowledge recombination, facilitates knowledge sharing and access, and provides broader contact with internal

talent and capabilities. However, the impact of structural holes on individuals is not entirely positive. Xiao et al. introduced structural hole theory into different cultural contexts to study its impact on four high-tech companies in China, where building the right relationships and integrating into the team is critical for career and business success or survival [9]. Those situated between two in-groups are often not trusted by either group—they may be seen as outsiders not worthy of in-group treatment. As the Chinese saying goes, crossing structural holes is like stepping on two boats, which is one of the most socially deprecated acts, hence there is a negative correlation between structural holes and employee performance in collectivist cultural organizations.

At the team level, Balkundi et al. found in their study of 19 teams in a woodworking enterprise that both extremes of structural homogeneity (few structural holes) and structural heterogeneity (many structural holes) could damage team performance [8]. Teams without structural holes face the risk of lacking new ideas and innovative problem-solving solutions, but too many structural holes can fragment a team, making coordination and communication difficult. The authors proposed and demonstrated that moderate structural diversity within teams positively correlates with team performance. Yang et al. sought to investigate the network characteristics of quantum innovation teams and their impact on innovation performance. They selected three high-level quantum innovation teams from the University of Science and Technology of China as their research subjects and constructed panel data of 143 researchers from 2010 to 2019. The study found that degree centrality, closeness centrality, and betweenness centrality of high-level quantum innovation team networks have a positive impact on team innovation performance. Structural holes do not directly affect innovation but positively moderate the impact of the three centralities on innovation performance [11].

At the organizational level, the most research has been published compared to the other two levels because both individual and team innovations ultimately converge on corporate innovation, all to enhance the innovative performance of enterprises. The current literature on structural holes and corporate innovation is divided into three categories.

The first category of literature posits that structural holes can promote corporate innovation. Structural holes, or the spaces between non-redundant social groups, may bring informational and control benefits to the actors that bridge or span these discontinuities [1]. Informational benefits provide actors with unique and diverse information, while control benefits enable actors to gain greater bargaining power and control over resources or outcomes. Thus, actors bridging many structural holes can quickly acquire key resources and control over others, displaying greater performance than those bridging fewer holes. Based on this logic, previous research proposed and found that structural holes obtained by firms in strategic alliances have a positive effect on their innovation performance for two reasons [12,13]. First, compared to other firms, those filling structural holes may use the information advantage of the structural holes to engage in more innovation activities. They can get different and valuable information from remote parts of the network, which can be combined to create new knowledge and insights [14]. Moreover, they may hear about upcoming opportunities and threats more quickly than others and discover potential exchange partners and allies [15]. With these information advantages, firms bridging structural holes can seize new innovation opportunities and reduce the risks associated with innovation activities. Second, compared to other firms, those filling structural holes may engage in innovation activities at a lower cost through control benefits. Control benefits allow firms to gain greater bargaining power and control over resources or outcomes through intermediation. By utilizing control benefits, intermediary firms can make decisions favorable to themselves in strategic alliances with other firms. Therefore, firms bridging structural holes in alliance networks can improve the efficiency of their innovation activities and produce greater innovation performance by leveraging their control over external resources. Firms that obtain more structural holes in alliance networks will learn and adapt to surrounding technologies and market practices more quickly due to the benefits of information and control [16]. Organizational learning, enhanced by structural holes, is particularly valuable for firms

engaged in innovation tasks, such as high-tech firms, because they can better understand dynamic technologies and absorb new knowledge faster than their competitors.

The second category of literature opposes the first, suggesting that structural holes have a negative impact on corporate innovation [19, 20]. A closed network with strong cohesion and fewer structural holes can generate trust among firms and help prevent malfeasance or opportunistic behavior in the face of information asymmetry or incomplete disclosure [19]. Firms with many structural holes may affect their trust relationships with partners, thereby impacting innovation. Moreover, when innovating, firms with many structural holes may possess disparate or conflicting knowledge, which can negatively affect the focal firm's implementation of innovation. When implementing innovation, the focal firm may need to connect this diverse knowledge with internal knowledge or absorb it into the current technological trajectory, which requires a significant amount of time and energy, leading to high integration costs and a negative impact on innovation.

The third category of literature considers both scenarios, taking different contexts into account. First, corporate innovation can be divided into exploratory and exploitative innovation. Exploratory innovation refers to the pursuit of new knowledge, developing new products and services to meet the needs of emerging customers or markets. Conversely, exploitative innovation refers to extending or changing existing products and services based on existing knowledge to meet the needs of current customers and markets [21]. Zhang et al. explored the impact of structural holes on firms' exploratory technical innovation and exploitative innovation and considered the moderating role of trust. Their empirical study confirmed that network structural holes have a positive impact on firms' exploratory technical innovation activities and that trust plays a positive moderating role between them. If a firm needs to improve its level of exploratory technical innovation, it needs not only to occupy more network structural holes but also to enhance the level of trust with other firms in the network [31]. Zang et al. tested a sample of 305 key U.S. computer companies and 6,894 alliances from 1993 to 2004, demonstrating that structural holes positively affect firms' exploratory innovation but hinder their exploitative innovation [22]. A company's network strategy should depend on the type of innovation implemented. For companies dealing with new products or exploring new markets, brokerage positions may be more suitable because firms must be able to access a wide range of external resources. However, a densely connected network may be more appropriate when companies try to offer products and services to existing customers or improve existing products and technologies because dense networks encourage in-depth communication and fine-grained knowledge acquisition. Second, the impact of structural holes on corporate innovation performance is influenced by various factors. Kim et al. empirical study proved that the positive impact of structural holes is often relatively strong in companies with lower status, and as the company's status improves, its negative impact becomes stronger [25]. Vasudeva et al proved that the impact of structural holes on innovation performance is influenced by national institutions [24]. When companies or their alliance partners are located in highly corporatist countries, or under certain combinations of brokerage and partner corporatism, firms bridging structural holes gain the most significant innovation benefits.

4.3. The Mechanism of Structural Holes

In the consolidation of research on the relationship between structural holes and innovation performance, it is evident that structural holes influence innovation in various ways, acting as both a predictor and a moderator. For example, Zhang et al. treated structural holes as a predictor and trust as a moderating variable to explore their effects on firms' exploratory and exploitative technical innovation activities [31]. While Kim et al. used structural holes as a predictor, they also considered the moderating role of a firm's status [25]. Zang directly investigated the impact of structural holes on exploratory and exploitative innovation as a predictor variable [22].

Moreover, studies have found that structural holes can positively moderate the impact on innovation performance. For instance, Yang et al. treated structural holes as both a predictor and a moderator, finding that while structural holes do not directly affect innovation, they positively modulate the impact of degree centrality, closeness centrality, and betweenness centrality on

innovation performance [11]. Structural holes have also been found to affect absorptive capacity and network knowledge diversity, thereby impacting innovation performance. Zhou et al. positioned a firm's absorptive capacity as a predictor, with structural holes as a moderator, demonstrating that structural holes positively regulate the impact of absorptive capacity on innovation performance [27]. Wen examined related and unrelated network knowledge diversity as predictor variables, with exploitative and exploratory innovations as outcome variables, finding that structural holes in inter-firm R&D networks negatively moderate the impact of related network knowledge diversity on exploitative and exploratory innovation, but have a positive effect on the impact of unrelated network knowledge diversity on these types of innovation [28].

In summary, the influence of structural holes on innovation performance is a complex issue that requires a comprehensive consideration of multiple factors.

5. Conclusion and Future Recommendations

Since the introduction of structural hole theory, management scholars have extensively studied it. Through keyword co-occurrence analysis of related domestic and international research, it is evident that there is widespread interest in the impact of structural holes on innovation performance. Research has shown that structural holes influence innovation at individual, team, and organizational levels. However, it is important to note that the impact of structural holes on innovation performance is not a simple linear relationship, nor is it strictly positive or negative. When considering the impact of structural holes on innovation, multiple factors such as the type of innovation (exploratory vs. exploitative), institutional differences, and the firm's position within the social network must be considered.

Moreover, structural holes not only serve as predictor variables affecting firm innovation but can also act as moderators. The impact of structural holes on innovation varies across different contexts. It should be noted, however, that current research on structural holes and firm innovation has its limitations. Most studies are confined to a single country or industry, which may limit the generalizability of the results. Different countries and regions, with their distinct institutions, cultures, and backgrounds, might see varied impacts of structural holes on innovation performance. Additionally, studies across different industries might yield differing results.

Future research could consider conducting more in-depth explorations across various contexts and industries to better understand the relationship between structural holes and firm innovation. This could involve comparative studies that include multiple geographical locations and sectors to discern whether and how contextual factors modify the effects observed. Such studies could help clarify the conditions under which structural holes most significantly influence innovation and whether these effects are consistent or vary significantly across different settings.

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